California AUAV Air Pollution Profiling Study (CAPPS) and California Rain and Snow Experiment 2 (CRAISE-2)

California AUAV Air Pollution Profiling Study (CAPPS)

Tasks 1,2,3,4,6

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1. STATEMENT OF WORK for the California AUAV Air Pollution Profiling Study (CAPPS)

1.1. Introduction and Identification of the Problem

Concern over climate change is of increasing public interest since the consequences can be far reaching. Climate change is closely associated with air pollution, which makes it an important topic to California. Air pollution in California arises from the combination of the energy needs of a large population and its unique regional meteorology/climate. The large population requires power generation, accompanying industry, and a vast transportation system focused at the individual level (i.e., automobiles). Adding to the pollution caused by the large population are the effects of a dry climate that promotes the occurrence of wild fires and a characteristic meteorology (in Southern California) that has a tendency to retain pollution within the region rather than exporting it. Recently, the contribution of pollution transported across the Pacific from the Asian continent has also been identified as a significant source of pollution in California. The effects of this pollution have traditionally applied to the areas of health, visibility, agricultural yields and acid rain; however, concerns also extend to the regional climate such as the dimming of the amount of sunlight that reaches the ground, atmospheric heating or cooling due to the aerosol reflecting and absorbing sunlight, reduced snowfall, and even the accelerated melting of the winter snowpack. These outcomes can in turn affect many factors important to the citizens of California such as agricultural plant growth, solar- and hydropower generation, and even the frequency of forest fires (Jacobsen, 2004).

Both an increase of heat retaining gases (i.e., greenhouse gases) and the modification of the amount of cloud cover affect the incoming radiation and thus results in climate changes. This process of altering the amount of solar energy retained by the atmosphere is termed radiative forcing. Combustion of fossil fuels creates carbon dioxide gas, the most common greenhouse gas, and byproducts such as carbon monoxide (CO) and hydrocarbons affect air quality and health. Carbon monoxide also serves as a tracer gas and can be used to identify air masses influenced by combustion processes. Ozone, a photolysis byproduct of nitrogen oxides and hydrocarbon pollution, is typically of concern for its affect on health and as an oxidant that accelerates the degradation of materials such as rubber. In addition, ozone is a significant greenhouse gas that contributes about 1/3 the solar radiative forcing as does carbon dioxide gas; therefore, ozone has a significant effect on climate change (IPCC, 2001). Moreover, ozone plays a substantial role in the formation of airborne particulate pollution, which also serves an important role in climate change.

Particulate pollution also has the ability to affect climate (Charlson et al, 1992) and the hydrological cycle (Ramanathan et al 2001). Particles change climate via three pathways: 1.) scattering incoming solar radiation back into space (cooling direct effect), 2.) black material (soot) absorbs light and heats the surrounding air (heating direct effect, and 3.) altering the reflectivity and lifetime of clouds (indirect effect) (Twomey, 1977; Lohmann and Feichter, 2005). Consequently, the chemistry and the color (i.e., darkness) of an aerosol particle determine the magnitude of climate influence. Particles from a diesel engine or smokestack may be dark in color due to large amount(s?) of black carbon (BC) and will exert a positive radiative forcing (heating). A particle formed from photochemical reactions of hydrocarbons will typically be white and will scatter sunlight. Other particles may be water soluble and may alter the brightness and lifetime of clouds (indirect effect) (Corrigan and Novakov, 1999). In addition to climate change, the combinations of these radiative effects result in a decrease of sunlight reaching the surface, which is known as dimming (Ramanathan et al, 2005c). The reduction of sunlight at the surface will have an impact on solar power generation, wind speeds and on agricultural yields (Jacobsen and Kaufman, 2006; Stanhill and Cohen, 2001).

Frequent monitoring of pollution in the atmosphere can give insight into the potential for climate change over a region. Several long-term monitoring programs exist in California that produce data that can be applied towards studies on climate change. Air quality issues are often intimately joined with issues of climate change, and data from sites oriented towards air quality monitoring can often be utilized for climate analysis. Likewise, much of the data collected for climate change studies can also be applied towards air quality studies. Nonetheless, most monitoring of air quality produces data for only surface locations and neglects to provide data pertaining to other layers of the atmosphere. The surface layer does not necessarily have the same amount of pollution as layers at higher altitudes. Information on the pollutant concentration from these other atmospheric layers is necessary to provide a more complete estimate of regional climate change. The use of Autonomous Unmanned Aerial Vehicles (AUAVs) offers the ability to do safe, frequent, and inexpensive sampling of different atmospheric layers.

1.2. Traditional Ground Based Monitoring of Aerosols

The standard method for measuring air pollution consists of sampling air at the surface level. One large, well-established system for monitoring air pollution throughout the United States is the IMPROVE (Interagency Monitoring of Protected Visual Environments) network, which is an extended air quality monitoring network positioned throughout the US National Park System and was originally installed to assess trends in visibility. The information gathered from this network can also be used for air quality and climate studies. Figure 1 shows the black carbon and organic carbon (OC) particulate concentration observed at Yosemite National Park over the past 18 years. A clear annual pattern is apparent as both black carbon and organic carbon particulate concentrations increase in the summer months. This increase is likely due to a number of factors associated with the warm conditions of the summer months including increased heavy diesel traffic, vacation traffic, campfires, and forest fires. The same repeating pattern is also detectable in other IMPROVE site locations in Southern California. Both Joshua Tree National Park and Agua Tibia (near Escondido) show the same annual pattern of increased carbonaceous particulates during the summer as seen in Figure 2 and Figure 3, respectively. These last two sites are not as affected by road closures and winter conditions as Yosemite, but transportation and recreational activity certainly increase during the warmer months. A large influence on the increase in carbonaceous particles may be due to regional forest fires.

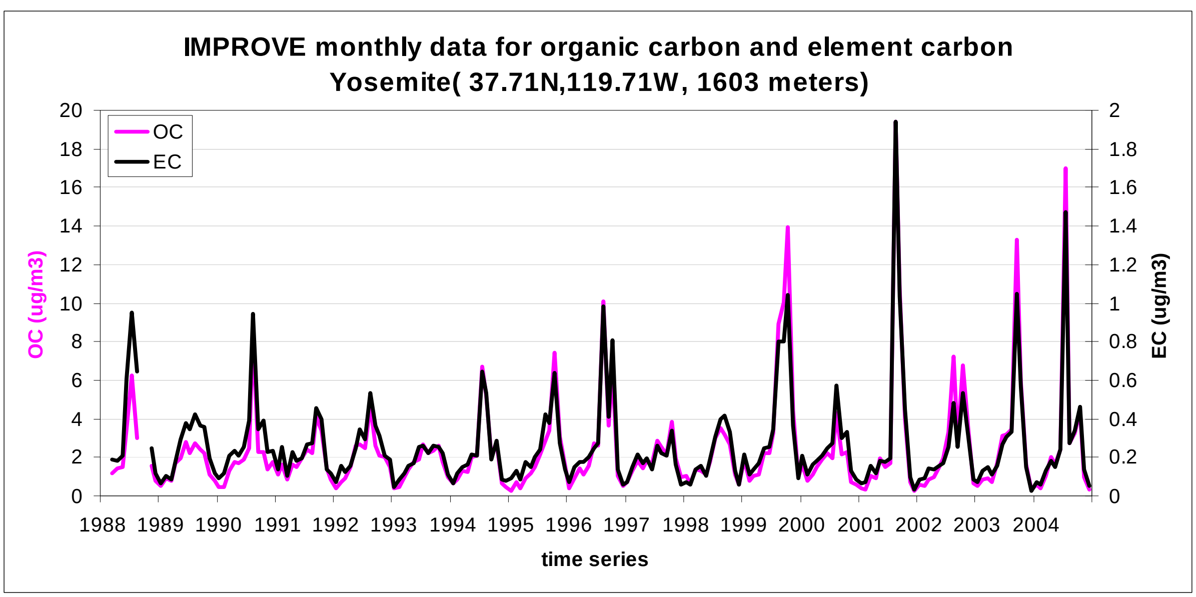

Figure 1. Organic and black carbon particulate concentrations at Yosemite National Park.

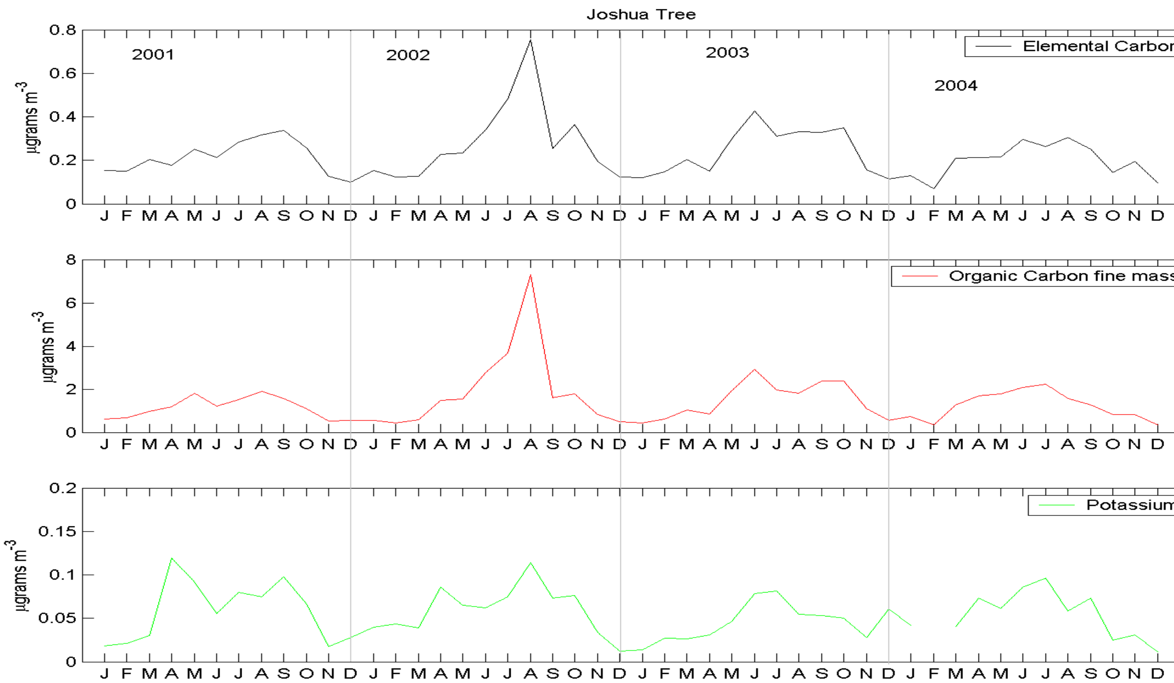

Figure 2. Particulate composition trends at Joshua Tree National Park.

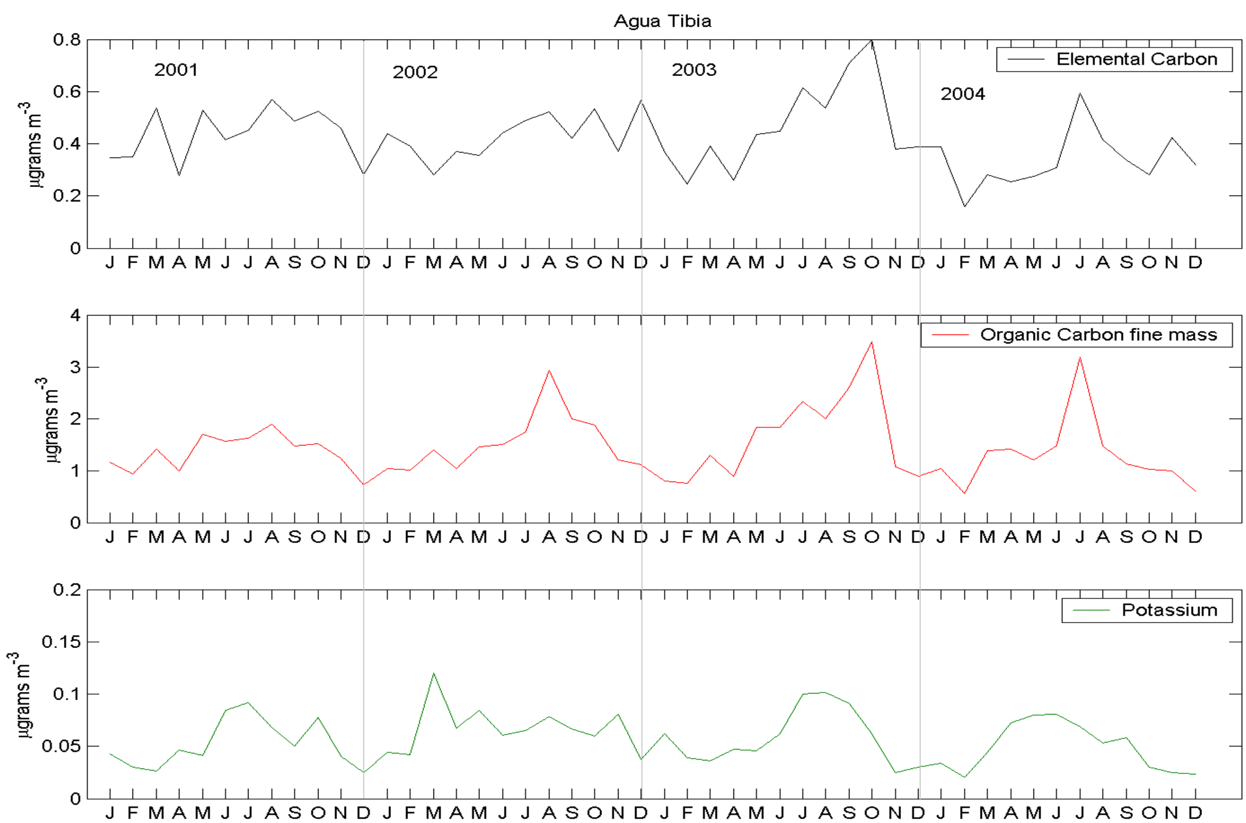

Figure 3. Particulate composition measured at Agua Tibia (San Diego County).

The fractional influence of forest fires and other biomass burning can be deduced by looking at the particulate concentration of potassium. Potassium is generally accepted as a marker for the burning of biofuels (wood, grass, etc.) In Figures 2 and 3, potassium also exhibits the same characteristic pattern as OC and BC which suggests that much of the OC and BC spike during the summer and early fall comes from forest fires.

The historical wild fire pattern for California is shown in Figure 4 and clearly indicates that wild fires are a major source of pollution during the late summer and early fall months. The frequency and scale of the fires revealed by the figure suggests that OC and BC in the smoke plumes may have a significant effect on regional climate via solar heating of BC, shading of the surface by OC, and augmenting clouds. Furthermore, the warming of the atmosphere by BC at higher altitudes may serve to stabilize the boundary layer and increase the time that pollution stays aloft. Other studies have shown that smoke can extend the lifetime of clouds by inhibiting rainfall (Rosenfeld et al, 1999). Figure 5 shows a satellite image from the MODIS instrument onboard the NASA Aqua satellite showing the recent Day Fire that persisted for several weeks. The smoke plume covers a large region and will certainly impact the incoming solar radiation over a large region and may have an effect on cloud formation and longevity (Novakov and Corrigan, 1996). While forest fires may be contributing to climate change, they may also be affected by changes in the climate. The forest fire frequency in the Western US has been increasing over the last quarter century and this increase has been linked to higher average spring and summer temperatures and earlier spring snowmelts (Westerling et al, 2006).

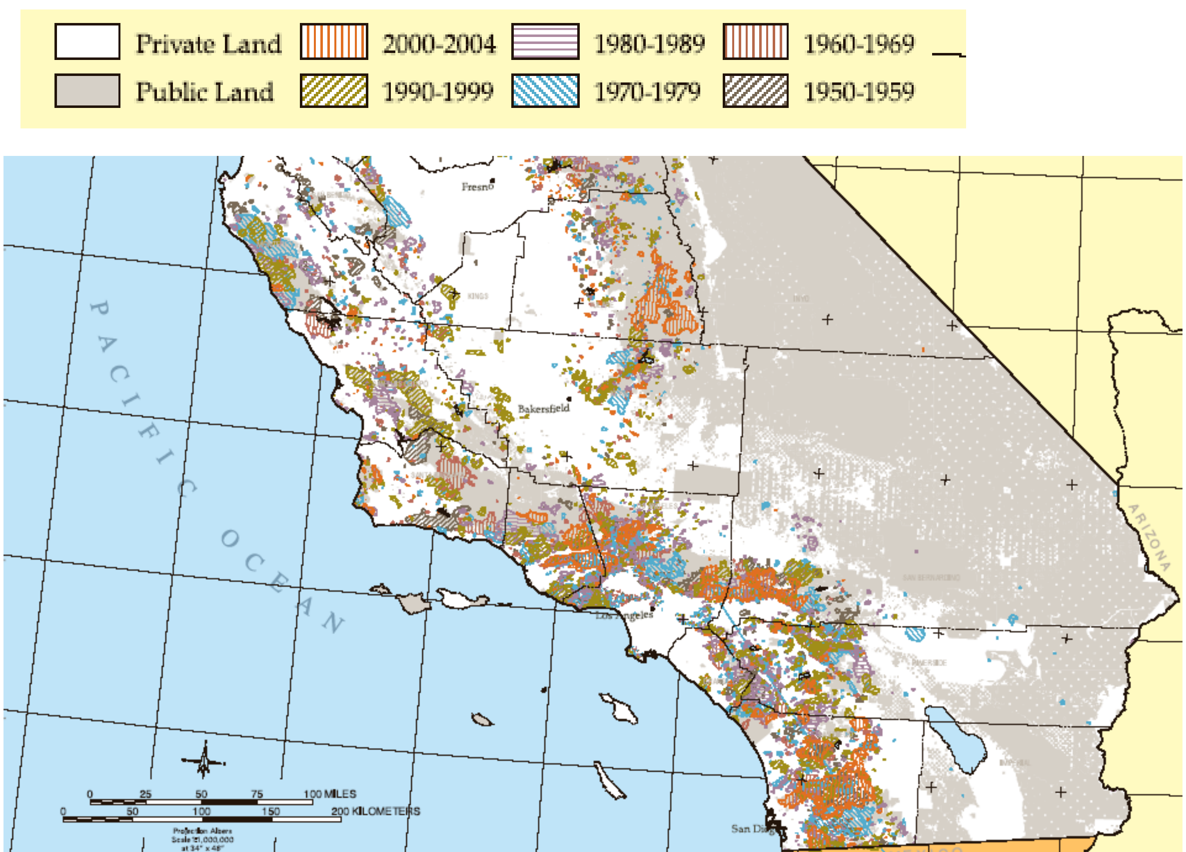

Figure 4. California Department of Forestry map for wild fire occurrences in California.

Figure 5. MODIS image of Day Fire (Sept 26, 2006).

The IMPROVE Network is a surface level monitoring system. As a result, pollution released locally will typically have a greater influence on these measurements and the results may not reflect the concentrations over the larger region. Pollution carried from elsewhere may be at higher altitudes and will therefore not be detected by the ground based measurements. A large plume of material can easily pass overheard without the ground based samplers ever detecting anything. Assuming that measurements at the surface reflect the entire column of air is a limitation of ground based measurements everywhere.

1.3 Gas Pollutants

Ozone and CO at ground level are harmful pollutants associated with human activity. While CO in the open ambient atmosphere rarely presents a threat to health, high ozone concentrations in urban areas certainly endanger health and damage ceratin materials such as rubber. Ozone is also naturally produced at higher altitudes through the photochemical splitting of oxygen molecules by UV light. These reactions mainly occur at higher altitudes where the intensity of ultraviolet radiation is most intense. Carbon monoxide is a byproduct of incomplete combustion and can serve as a marker showing that an air mass has been exposed to urban, industrial, or biomass burning sources. Other important gas pollutants, such as sulfrur dioxides and nitrogen dioxides are not incorporated into this study due to current limitations in miniaturized detection equipment.

Ozone and CO are routinely measured at the surface as part of ubiquitous air quality monitoring systems that exist in every part of the country. Studies over the East Coast of the US to measure gas concentrations at altitude using manned aircraft have found that the concentration of ozone in the free troposphere was not directly influenced by the concentrations below the boundary layer (Taubman et al, 2006.) The free troposphere concentrations were most associated with long-range transport from other regions.

1.4 Sources of Pollution and Long Range Transport.

Pollution above the boundary layer can often travel great distances. Figure 6 shows the long-range transport of pollution from Asia across the Pacific (Hadley et al, 2006). The figure uses data from the MODIS instrument that measures the aerosol optical depth, or amount of sunlight that is absorbed and scattered by airborne particles. This intercontinental plume was studied by our team at the Scripps Institution of Oceanography using manned aircraft over the Northern California coast in 2004 as part of the CIFEX (Cloud Indirect eFfects EXperiment) campaign. From that work, our group (Center for Clouds, Chemistry, and Climate) have recently submitted a paper providing evidence that more than 75% of the black carbon over the west coast during the spring months originates from Asia (Hadley et al, 2006). This amount of black carbon is estimated to contribute 1.1 and 0.5 watts/m^2 of radiative forcing for clear and cloudy sky conditions at the top of the atmosphere compared to a radiative forcing by CO_2 of 1.5 - 2.0 watts/m^2 (CO2 is distributed uniformly across the entire globe while BC pollution is more regional.) While the paper is restricted to the spring months, similar transport cannot be ruled out during the other months of the year. Tracing the wind patterns backwards offers a clue as to the impact of long-range transport on California air quality and regional climate effects.

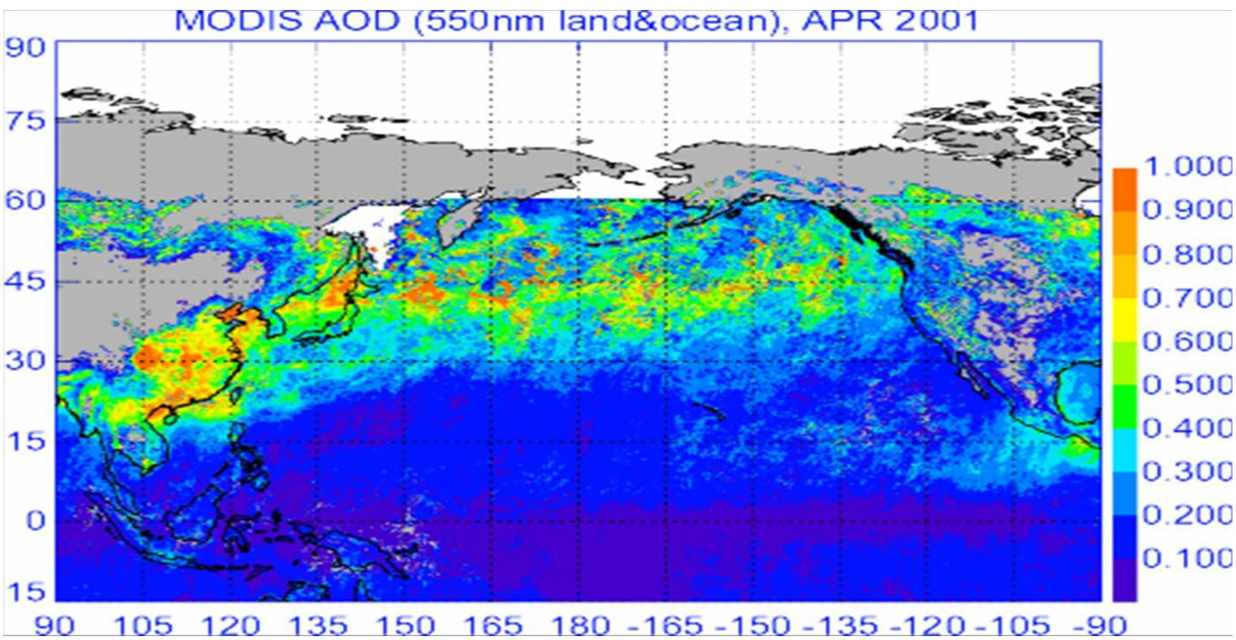

Figure 6. Aerosol optical depth shows significant transport of particulate pollution from Asia to North America during Spring 2001. Aerosol optical depth data from MODIS instrument on NASA Aqua satellite.

Using the Hysplit (HYbrid Single-Particle Lagrangian Integrated Trajectory) model managed by NOAA, the origin of air masses arriving at a specific location can be estimated (Draxler and Hess, 1998). Figure 7 shows the nine-day history of an air parcel during Spring 2005 prior to arriving at Dryden/Edwards Air Force Base. The four different lines in each panel represent selected days during the month and the color of the lines indicates the altitude. These wind back trajectories reveal that the air mass arriving at Dryden at the higher altitudes passed over the Pacific Ocean and probably originated from Asia. Figure 8 presents the nine-day wind back trajectories for August of 2005 and shows that the air masses spent significant time circulating about Southern California and Northwestern Mexico. As a result, these summer wind parcels may carry pollution from urban regions of Southern California and Mexico. This pollution will likely influence the regional air quality and regional climate forcing.

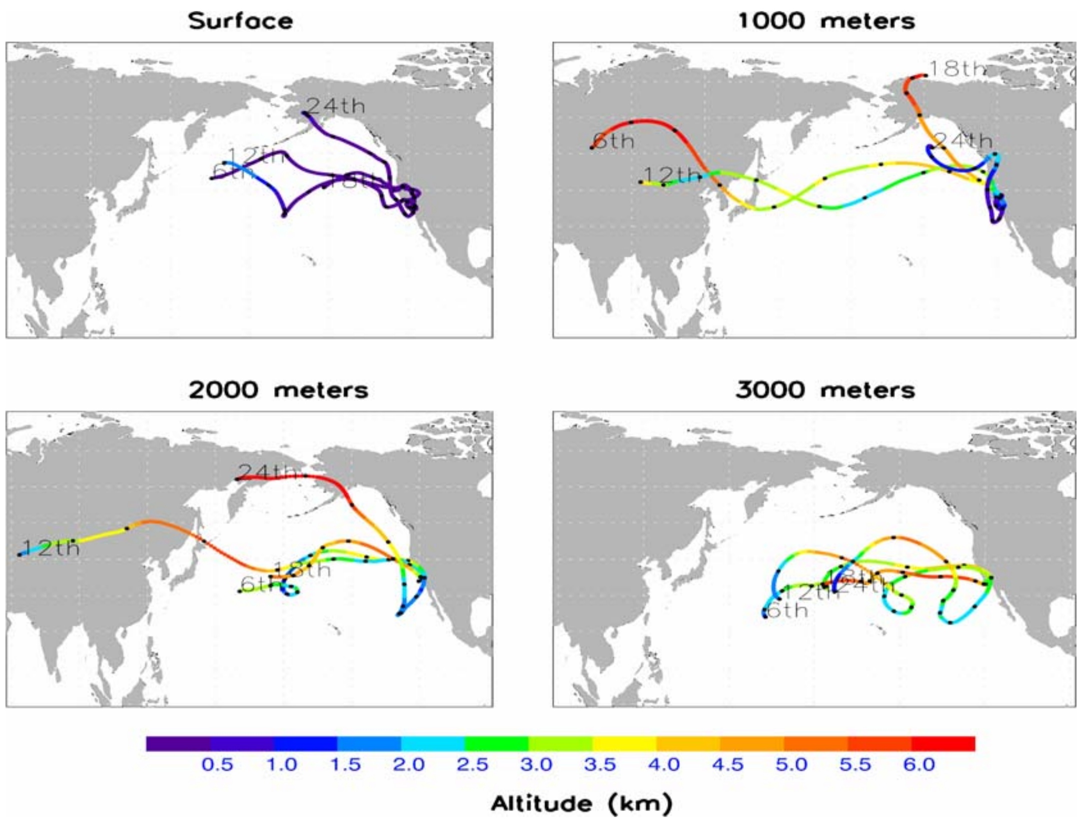

Figure 7. Nine-day back trajectories from Edwards Air Force Base for April 2005.

The material transported over the Pacific Ocean includes dust, aerosols, black carbon, and gases, such as ozone and carbon monoxide. Aerosols are partially removed on their weeklong crossing of the ocean by rain and dry deposition, yet many of the aerosols still survive the journey. Black carbon particulates (and other absorbing aerosols) are of particular interest due to the implication for regional climate change by the absorption of sunlight and it subsequent release as heat. This heating effect is magnified up to 300% when the absorbing material is contained within a cloud droplet (Mikhailov et al, 2006). Since aged aerosols are generally more water-soluble due to internal mixing and cloud processing, the BC arriving by long range transport will potentially be more likely than locally generated BC particulates to become incorporated into cloud droplets and thus have a larger impact on the regional climate. Moreover, as black carbon absorbs sunlight and warms the surrounding air, the boundary layer may become more stable resulting in further persistence of the aerosol pollution layers and an increased lifetime for water clouds. Finally, more climate effects may occur when the dry and wet deposition of black carbon accelerates the melting of the snowpack due to an increase in solar heating (Hansen and Nazarenko, 2004).

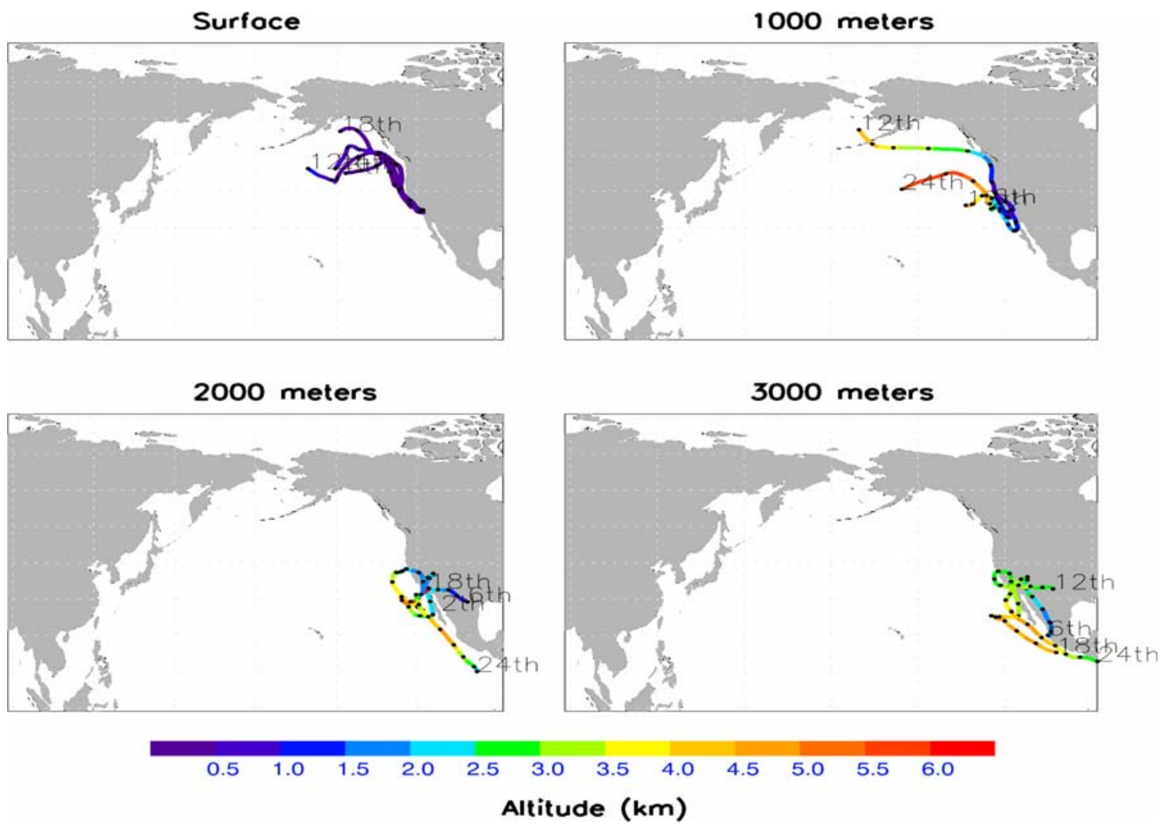

Figure 8. Nine-day back trajectories from Edwards Air Force Base for Summer 2005.

1.5. Importance of Vertical Profiling

To accurately characterize the amount of BC (or other pollutants) distributed at altitude requires taking measurements at different altitudes (termed as vertical profiling.) Examples of BC concentration profiles as a function of altitude are shown in Figure 9 (Corrigan et al, 2006b). These particular profiles were collected over the Maldives in March of 2006 using unmanned aircraft, or AUAVs, during the Maldives AUAV Campaign (MAC; Ramanathan et al 2006a).. For many of the days in March 2006, the concentration of black carbon detected at the surface failed to reflect the concentration seen at higher altitudes. From this data, it is evident that ground based measurements alone are not adequate for accurately capturing the amount of black carbon present in the atmosphere when long range transport is present. More relevant to circumstances over California is the fraction of BC originating from Asia as seen in Figure 10 (Hadley et al, 2006). The plot that pertains most to California is labeled '30N to 42N" (indicating the range of latitudes for California). These BC concentrations were obtained from the Chemical Forecast model (CFORS) at the University of Iowa (Uno et al, 2003). The model results predict that as the altitude increases, the fraction of the total BC that originates from Asia also increases. At ground level, BC that originates from Asia accounts for only 20% of the total measured BC while at 3000 meters altitude the Asian BC aerosol accounts for 75% of the total BC measured. Consequently, understanding the vertical distribution of BC will give an indication as to the contributions of BC from local sources and from long-range transport. Data from vertical profiling combined with wind back trajectories may help to sort out the original sources of the black carbon which may in turn help with determining approaches towards mitigation.

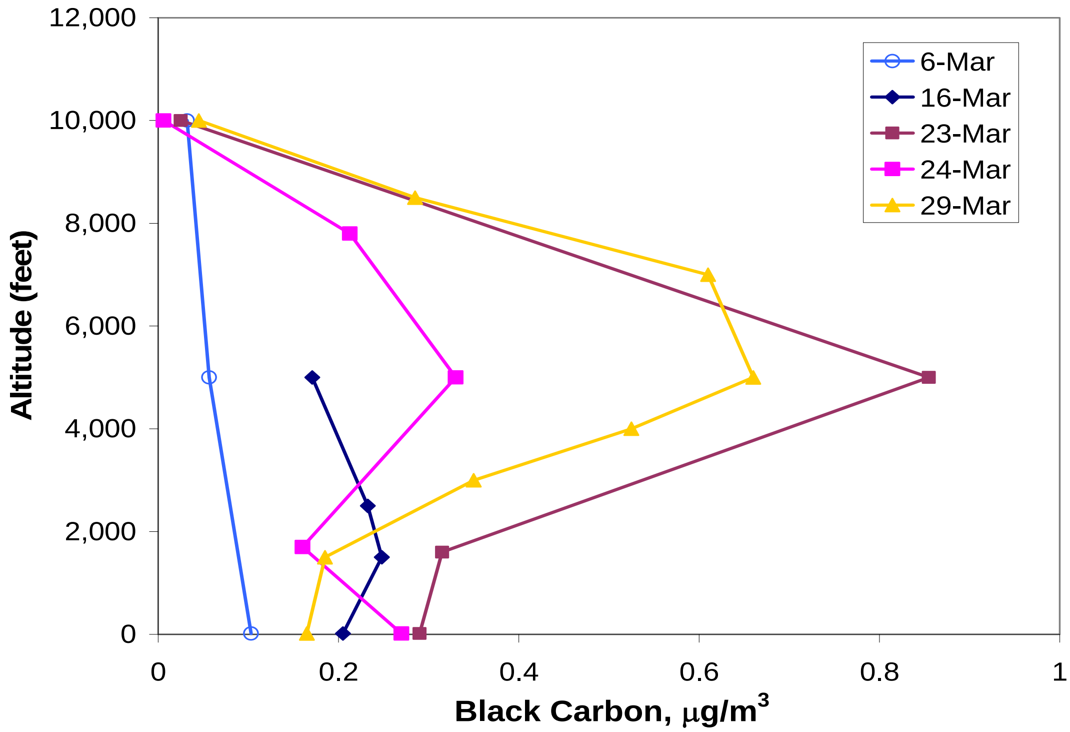

Figure 9. Vertical profiles of black carbon concentrations taken over the Maldives during the MAC experiment in 2006. (from Corrigan et al, 2006b).

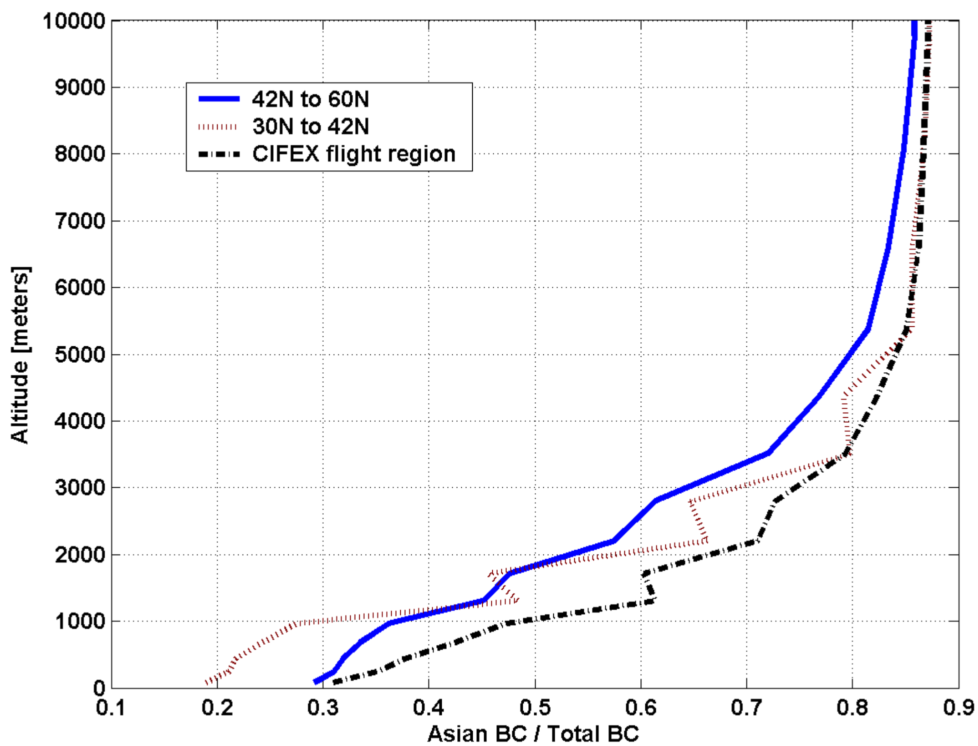

Figure 10. Vertical distribution showing fraction of Asian BC versus total BC. The region between 30N and 42N covers California. (from Hadley et al, 2006)

Ozone and CO gas may be carried long distances and several studies have established that significant concentrations of both ozone and CO are transported across the Pacific from Asia to the continental US (Goldstein et al, 2004; Bertschi and Jaffe, 2005; Liang et al, 2004). These pollutants are then added to the locally generated pollution in the United States. As long-range transport of pollution from Asia increases with the economic development of countries such as China, meeting air quality standards for California in the future may become more of a challenge (Hudman et al, 2004). Ozone and CO at higher altitudes would be more likely to have come from long-range sources while ozone below the boundary layer would most likely be attributed to sources within California. By measuring CO and ozone at different altitudes in conjunction with looking at wind back trajectories, sources of the pollutants may be partially identified. Moreover, the concentrations measured directly may be used to validate satellite measurements and models that attempt to predict/simulate the concentrations of ozone and CO (Heald et al, 2003).

1.6 Use of AUAVs to Monitor Air Pollutants

The limitation in assuming uniformly vertical atmospheric aerosol properties based on measurements taken at the surface has been recognized and addressed in numerous studies (Ramanathan et al, 2001; Huebert et al, 2003; Ramanathan et al 2006a; Corrigan et al, 2006a). Many of these studies utilized short term vertical profiling using manned aircraft. Most manned aircraft missions are expensive and involve risks to crews and operators. As a result, aircraft missions are typically only operated during intensive periods of one week to one month. In a few cases, small manned aircraft have been outfitted with aerosol instruments and used routinely to collect airborne data on aerosols (Andrews et al, 2004) Nonetheless, AUAVs offer the potential to execute routine airborne measurements in a less expensive and low risk manner. Our team at Scripps recently deployed AUAVs that successfully measured aerosol, cloud, and irradiance properties over the tropical Indian Ocean during the MAC campaign (Ramanathan et al 2006a and 2006b; Corrigan et al, 2006b; Roberts et al, 2006a). NASA, NOAA, and NSF have all demonstrated interest in future deployments of AUAVs to monitor the long range transport of black carbon and other pollutants from Asia to the Western United States. Expansion of AUAV measurements to other locations provides a potential opportunity for cooperation between state and federal agencies on important climate related issue.

2. SCIENTIFIC OBJECTIVES

The goals of this project (CAPPS) are to observe the temporal cycle of pollution over California at multiple altitudes. The aircraft flights will measure aerosol total concentration, black carbon concentration, ozone concentration, carbon monoxide concentration, temperature, and relative humidity between the surface (2000 feet asl) and 12,000 feet asl. The following goals will be addressed.

- Collect a seasonal record of aerosol, black carbon, ozone, and carbon monoxide pollution concentrations at altitudes up to 12,000 feet asl.
- To discriminate between California generated pollution and long-range transport from other regions.
- Look at the impact of pollution layers on radiative forcing to quantify the amount of solar dimming.
- Deploy and validate novel miniaturized instruments and UAV platforms for advanced, state-of-art measurements

Addressing the first three questions will help to obtain a more accurate picture of regional climate change potential and the influence of long-range transport of pollutants on California.

3. PROJECT METHODOLOGY

3.1. California AUAV Air Pollution Profiling Study - CAPPS

CAPPS will be the first study of its kind in California to collect routine vertical profiles of aerosol and gas, pollutants in conjunction with radiative forcing measurements. Moreover, CAPPS will be the first study of its kind anywhere to incorporate AUAVs in routine atmospheric measurements. We are proposing a 9 month campaign to conduct vertical profile measurements of aerosol and gas pollutants over California. The flights would occur at a frequency of either once a month to once every two weeks depending upon available resources. Certain periods of intensive operation for observing specific fire events or Asian dust plumes may warrant multiple flights within a one-week period. Our group has excellent experience with utilizing AUAVs to collect data for atmospheric science objectives as demonstrated with the recently executed MAC campaign (Corrigan et al, 2006; Roberts et al, 2006).

3.2 Maldives AUAV Campaign.

From March 6 to March 31, 2006, the Scripps team (Ramanathan et al 2006a) probed the polluted atmosphere over the N. Indian Ocean with light-weight Autonomous Unmanned Aerial Vehicles (or AUAVs) fully equipped with instruments (Fig. 11). This AUAV campaign launched from the Maldives laid a solid foundation for developing AUAVs as an advanced platform for atmospheric research. The experiment, called the Maldives Autonomous unmanned aerial vehicle Campaign (MAC), focused on observing the particle-cloud-solar radiation interactions. During the four weeks in March 2006, we proved that lightweight AUAVs are uniquely suited to conduct such an experiment. MAC logged over 120 flight hours that included 55 takeoffs and 18 science missions. The science missions collected data on pollution and dust transported from S. Asia, Arabian and SW Asian deserts and their impacts on global dimming at the sea surface, the energy absorbed in the atmosphere and cloud properties. We made direct measurements of the role of black carbon in the solar heating of the atmosphere. Hundreds of polluted and dusty shallow cumulus clouds were penetrated with the in-cloud aircraft. The above cloud and below cloud AUAVs were stacked within ten seconds of the in-cloud UAV with minimal pitch such that reliable solar radiation measurements could be made. The campaign as well as publications and video demonstrations of the flights are given at the following website location: http://www-abc-asia.ucsd.edu/MAC/secure/Index.htm

Figure 11. MAC experiment aircraft in the Maldives**.**

The MAC campaign demonstrated the practical use of AUAVs to monitor aerosols and other airborne pollutants. The proposed project of profiling vertical distributions of aerosols over California would utilize those same proven aircraft platforms and instrumentation used during the MAC campaign as well as a limited number of new instruments. Moreover, this project would produce a record of monthly vertical profiles to study long-range transport of pollutants into California and would be the first ever experiment of its type utilizing AUAVs.

3.3 Sampling Location.

Currently, the FAA does not allow unmanned aircraft to fly within United States public airspace without severe limitations, but the FAA is slowly developing new procedures. Consequently, the best locations for sampling routinely and at the high altitudes that the science requires would be airspace controlled by the US military or partners of the military, such as NASA. As a result, we have identified a specific site in California that serves a good balance between logistical and scientific interests. The NASA Dryden center at Edwards Air Force Base located 80 miles north of Los Angeles offers a centralized location in California. The map location of Edwards AFB/NASA Dryden and a satellite view of the flight operations box are shown in Figure 12. The Dryden facility is situated in high desert that is impacted at the surface by pollution from both Los Angeles and the lower San Joaquin Valley. Above the boundary layer, some local pollution and long-range transport will be observed. This facility offers access to unrestricted airspace in which an AUAV can operate. In addition, the NASA facility offers exceptional support personnel onsite. Use of this location allows for rapid and inexpensive access to achieve high altitude flights. As the FAA develops protocols for flying AUAVs in civilian airspace, we will explore the option of expanding these routine operations to other locations of scientific interest. Another possible flight location that is being investigated would be the Central Valley north of Sacramento since this area is more likely to be exposed to Asian pollution plumes; however, use of this location is dependent upon securing flight clearances with the FAA and/or military. Initial flights (first 2-3 months) will still need to be done at the NASA Dryden facility in order to develop routine operations under more controlled conditions. Based upon success, we will then approach CEC for sponsorship to allow flights in other military or FAA controlled airspace.

Figure 12. Edwards AFB/NASA Dryden a) location in California (red star) and b) flight operations area.

3.4 Flight Operations.

Flight operations will be primarily directed by NASA Dryden personnel. A flight of one to two aircraft (depending upon payload requirements) would be launched in the evening (8PM-12AM) from NASA Dryden. The flight would rapidly climb to 12,000 feet and then descend in roughly 2000 feet increments every 30 minutes. Total flight time would be around 4 hours. The same flight would then be flown again the next morning (8AM to 12PM). A flight may consist of one or possibly two airplanes depending upon the payload weight with the new instrumentation.

The flights would require 5 people to execute. 1.) One payload scientist who will be responsible for the instrumentation and data for the flight. 2.) One flight mission leader who will be responsible for the overall flight, including the aircraft launch, flight, and recovery. The flight mission leader will operate the ground station that controls the aircraft in flight. 3.) One RC (radio control) pilot/mechanic who will be responsible for piloting the aircraft during launch and recovery. The pilot/mechanic will also prepare the airplane for flight. 4.) A flight operations engineer to handle ground facilities, maintain power sources, coordinate with the local controllers, and help with launch and recovery of the aircraft. 5.) One RSO (range safety officer) who will be independently responsible for ensuring the safe operation of the aircraft. The RSO will possess the independent ability to terminate the flight if the primary operator loses control of the aircraft. NASA will most likely provide the RSO and flight operations engineer due to the missions being executed at NASA Dryden and due to their experience with flight operations.

3.5 Flight Instrumentation.

The majority of the instruments and systems needed for this proposed project were developed for the

Table 1. AUAV instrumentation and payload configuration for aerosol, cloud, and radiation experiments

Instrument	*ID*	*Weight (kg)*	*Power (W)*	*Data acquisition*
Condensation Particle Counter	CPC	0.87	2.3	RS-232
Optical Particle Counter	OPC	0.27	5.4	RS-232
Aethalometer	AETH	0.85	5	A/D
MAAP*	MAAP	?	?	A/D
Pyranometer	PYR	0.17	< 0.2	A/D
Photosynthetic Active Radiation	PAR	0.29	< 0.2	A/D
Ozone Monitor*	O3	(0.6)	<4	RS-232
CO Monitor*	CO	(0.4)	<2	RS-232
Temperature / relative humidity	TRH	0.05	< 0.1	A/D
Data acquisition system	DAQ	0.65	10	--
Cloud Condensation Nuclei **	CCN	2	20	A/D
Aerosol inlet	AI	0.21	--	--

New instrument
***Limited deployment*

MAC campaign. The instruments were successfully flown on 45 scientific flights accumulating more than 120 research hours plus dozens of test flights and have proven to be robust and reliable. Our payload (about 4-5 kg per aircraft; see Table 1) includes instruments and data systems developed for lightweight AUAVs through NOAA and NSF grants to our group. For this proposed experiment, several new instruments will be added to the payload. Two gas monitors for monitoring ozone and carbon dioxide will be developed. We will also investigate improvements to the aerosol absorption measurements, which are currently collected using the aethalometer. Each instrument payload will be thoroughly tested and the validity of scientific results quantified before and during the experiment. Views of established instruments can be seen separately and mounted in the aircraft in Figures 13 and 14. Each AUAV instrument is described below.

Condensation Particle Counter (CPC): The CPC measures total aerosol concentrations (N_{CN}) between 0 and 10^5 cm^{-3} in the diameter range (0.01 μm < D < 1.0 μm). The CPC serves as a reference for comparison with other aerosol measurements, and as an indicator for clean versus polluted regimes. The Model 3007 is TSI's smallest CPC and has been integrated into the fuselage of the AUAV. To reduce weight and volume by over half of the commercial version, the CPC engine, electronics, filters and pumps have been repackaged into a lightweight enclosure with the sample line attached to the aerosol inlet.

Optical Particle Counter (OPC): The OPC measures ambient aerosol size distributions between 0.3 and 3 μm diameter. Since aerosols cover a wide range of particle sizes, it is fundamental to have an understanding of the size distribution. The MetOne OPC has been repackaged.

Pyranometer (PYR): The pyranometer accurately measures total hemispherical solar irradiance for a broad spectral range between 0.3 – 2.8 μm. Downward solar irradiance is the fundamental quantity from which the earth obtains its energy and is measured by an upward-facing horizontal pyranometer. Conversely, a downward-facing pyranometer measures the amount of downward solar irradiance reflected by clouds or the earth's surface. The ratio of upward and downward solar irradiance yields the albedo.

Photosynthetic Active Radiation (PAR): The PAR sensors measure total hemispherical solar irradiance for a narrow spectral range between 0.4 and 0.7 μm. Downward and upward-facing sensors are installed.

Aethalometer (AETH): Light absorbed by aerosol particles reduces the amount of sunlight reaching the earth's surface while simultaneously heating the surrounding air. The aethalometer measures the absorption of the aerosol by depositing the particles onto a fibrous filter and observing the change in light transmission. The instrument is typically calibrated to give results in concentration of black carbon per volume of air, but the raw filter absorption data can be used to estimate the absorption coefficient for in-situ aerosols by using empirical corrections *[Bond et al., 1999]*. The aethalometer requires several minutes to generate a data point and requires level flight during this collection period.

Data Acquisition System (DAQ): An integrated data acquisition system connects to the instruments via an interface that supplies power and distributes the data signals to the computer. A single-board computer samples 16 channels of analog-to-digital (A/D), reads/controls up to six instruments via standard serial communication, and stores the data to a compact flash card. Several integrated circuits are embedded into the interface to increase its functionality as the central data system, including a GPS for time stamping and spatial coordination.

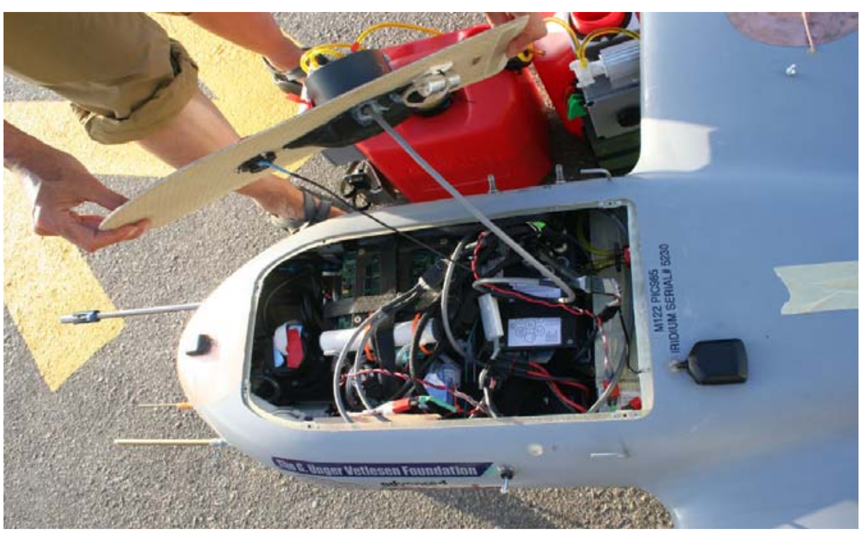

Figure 13: Payload bay for instrumented aerosol-radiometric AUAV.

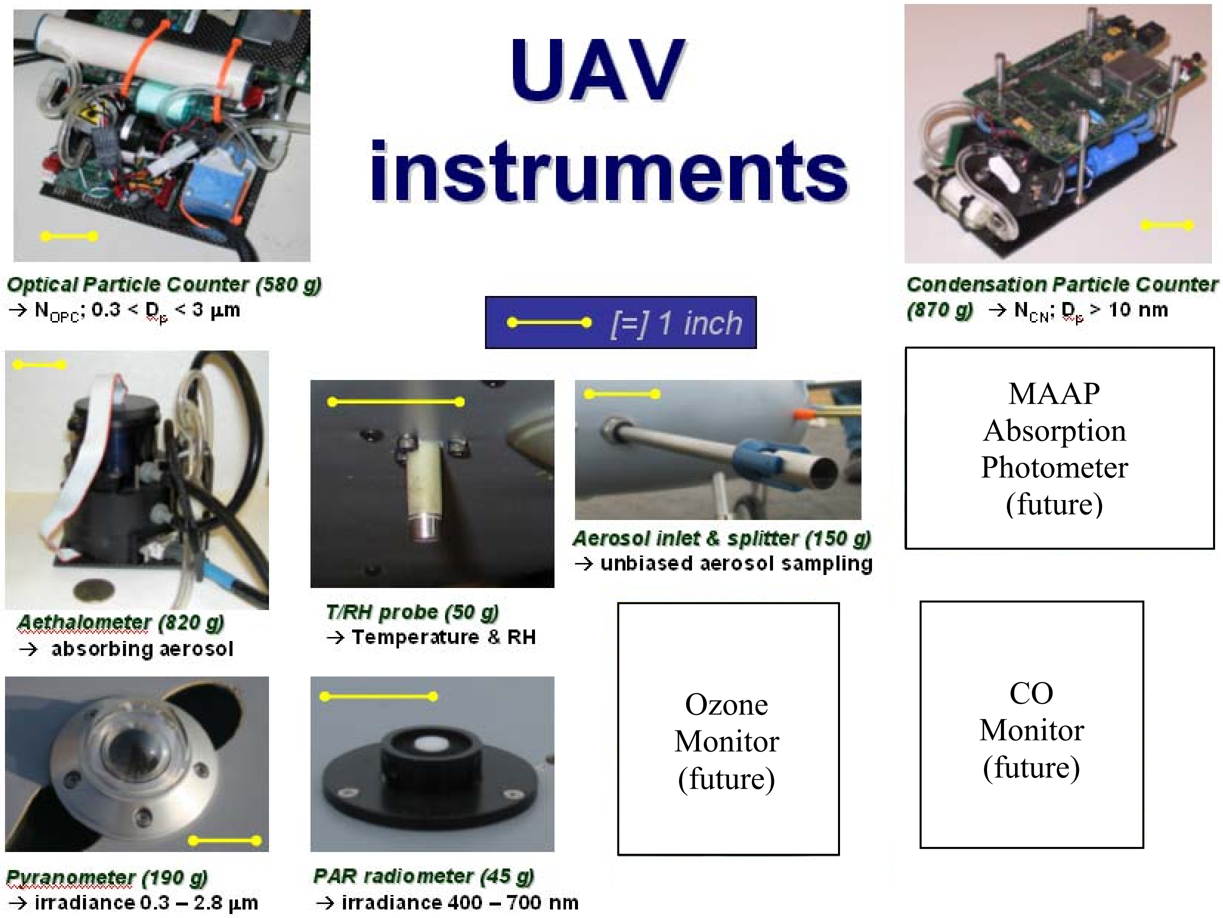

Figure 14: AUAV instruments for aerosol, radiometric and cloud microphysics platforms.

3.6 New Instrumentation

Several new instruments will be added to the standard aerosol package on the AUAV. An ozone monitor, a CO monitor, and an improved aerosol absorption photometer (Multi Angular Absorption Photometer.) *Ozone Monitor (O3):* Ambient concentrations of ozone gas will be monitored using an optical cell developed by 2B Technologies, Inc. Ultraviolet light with a wavelength of 254 nm is mainly absorbed by ozone gas and will pass through most other common ambient gases. The amount of absorbed light is proportional to the concentration of atmospheric ozone. The instrument is calibrated using a known standard contained within a gas cylinder. Measurements are obtained at a resolution of 1 ppb every 2 seconds.

Carbon Monoxide (CO): Ambient concentrations of carbon monoxide gas will be monitored using either an optical cell (sensitive, but bulky) or an electrochemical sensor (light, inexpensive, but less sensitive). This technology is still being evaluated and any final choice will include considerations for size, weight, and power consumption. Developing a <u>compact</u> instrument with adequate sensitivity is not guaranteed due to the low concentrations of CO gas in the ambient atmosphere.

Multi Angular Absorption Photometer (MAAP): The MAAP is a recent improvement over the standard aethalometer measurement. Interferences in the filter absorption method utilized by the aethalometer are directly accounted for using reflected light at two angles. The instrument is typically calibrated to give results in absorption coefficient, which can be converted to concentration of black carbon per volume of air using conversions found in the literature. The MAAP requires several minutes to generate a data point and this period is dependent upon the concentration of absorbing material in the atmosphere.

Cloud Condensation Nuclei Counter (CCN) for AUAV applications is currently under development at Scripps Institution of Oceanography. This instrument may be deployed on limited flights to obtain vertical profiles of CCN particles. Routine deployment is not feasible due to space and weight limitations.

3.7 Calibration and Validation of Instruments

Calibration and validation of the miniaturized aerosol, gas and radiometric instruments ensures the scientific integrity of the data. Most have been well-characterized and proven to perform reliably in previous AUAV experiments. The aerosol and radiation instruments will be compared with ground-based instruments operated simultaneously with flight missions. Moreover, instrumentation will be compared to standard instrumentation under controlled laboratory conditions. The gas phase instruments (CO and Ozone) will be calibrated using gases of known concentration.

Figure 15. ACR Manta Autonomous Unmanned Aerial Vehicle.

Table 2: Technical characteristics of the Manta AUAV.

Parameter	Value
Maximum Gross Takeoff Weight (MGTW)	52.0 pounds
Nominal Mission Takeoff Weight (NMTW)	45.0 pounds
Nominal Mission Endurance (87 octane gasoline)	6+ hours; 8+ hours w/new engine
Fuel	50:1 Gasoline/Oil Pre-Mix
Airspeed (Cruise @ NMTW)	39-90 knots
Airspeed (Dash - level flight @ NMTW)	70 knots
Airspeed (Max. Endurance @ NMTW)	39 knots
Airspeed (Stall @ NMTW)	35 knots
Airspeed (VNE @ NMTW)	110 knots
Navigation	DGPS/GPS, DGPS/GPS/INS*
Service Ceiling	16,000 feet MSL
Payload (EO)	PTZ daylight camera
Payload (IR)	PTZ IR camera
Command and Control Radio (C2)	Up to 2 Watt, Discrete/Frequency Agile, Military Band / ISM Band Radio Modem (TX/RX)
Command and Control Radio Range	15-20 nm, Line of Sight (LOS)
Video Transmitter	2 Watt (5 Watt Optional), S-Band FM Video TX with Optional 19.2kbps Data Carrier
Video Transmission Frequency Range	L-Band, S-Band
Video System Range	15-20 nm, LOS
Payload Capacity	Up to 15.0 lbs
Onboard Power	BA5590 LiSO2 Battery (one or two batteries can be installed), 14.4V, 15 Ah.
Nominal Mission Fuel Capacity	1.9 gallons
Engine	2-stroke reciprocating gasoline engine (87 octane) reverse rotation
Ignition	Electronic, Capacitive Discharge
Propulsion	18x12, tractor propeller (in reverse rotation)
Starting Method	Hand-held electric starter (12V)
Recovery	Parachute or Gear
Launch	Gear, Vehicle Based or Pneumatic Launcher
Shipping Container Size	49" x 52" x 24"
* - GPS/INS option available Q1, 2006??	

3.8 Description of the Manta Aircraft

(also see Advanced Ceramics Research (ACR) website http://www.acrtucson.com)

ACR's Manta offers a low-cost, compact, durable aerodynamic platform with extended flight endurance (see Fig 15.) The Manta offers an inexpensive alternative for groups whose budget cannot afford all the costs associated with larger AUAVs. The aircraft is capable of carrying a 5 kg payload during a 4 to 5 hour flight and can operate autonomously within a 200 km radius of its launch and recovery point. The aircraft autopilot uses satellite GPS to follow flight paths that can be uploaded at any time during a flight. The aircraft has the capability to fly over the horizon using Iridium satellite communication to update its flight path. The aircraft has a service ceiling of 16,000 feet and can climb to 10,000 feet in under 15 minutes. With only slight modifications, the Manta is able to carry both internal and external instrumentation and sensors.

4. RELEVANCE TO PIER CALIF. CLIMATE CHANGE PROGRAM AND LEVERAGING OF FEDERAL GRANTS TO THE PI (VR)

CAPPS will extend the new approach developed during the MAC project [*Ramanathan et al.*, 2006a; *Ramanathan et al.*, 2006b] as an atmospheric observing system and contribute to a better understanding of the distribution of aerosols and gas pollutants in the atmosphere. Scientifically, we hope to obtain new insights into the origins of these pollutants and the regional climate effects they influence. Using the results of this work, the Public Interest Energy Research (PIER) Program of the California Energy Commission (CEC) will be able to apply the findings towards estimating the potential future economic and ecological consequences of climate change for California. Existing research will also be used to link the aircraft data with satellite observations (MODIS; MISR and CALIPSO) and regional aerosol-transport models to infer aerosol forcing and ozone radiative forcing on regional (California and N America) scales. We have successfully conducted such integrations previously to produce regional scale aerosol forcing over S. Asia (Ramanathan et al, 2001).

Other benefits of this study include additional understanding of air quality and its relationship to pollutants at various altitudes. Air pollution carried from Asia by long-range transport may impact the already strict air quality standards in place in California. This means that California’s air quality standards will be surpassed more frequently as Asia develops economically.

AUAVs have the potential to become a major resource for scientific research. The capabilities of AUAVs have increased dramatically over the past few years, especially with improvements in autonomous flight performance. The ability to send an AUAV on a mission without the need for a pilot greatly expands the potential for extended measurements while simultaneously lowering the operational costs. Government agencies and private sector companies have employed AUAVs for surveying, atmospheric research, hurricane research, and volcanic plume sampling. CAPPS will serve to further develop the application of AUAVs to scientific research and to projects of public benefit that expand the scope of AUAVs beyond military applications.

5. TIME TABLE FOR PROPOSED PROJECT

The goals of this proposal are achieved by conducting airborne and ground-based measurements of aerosols, gases and irradiance. We propose a routine field project that extends through a 9 month period to observe long-range transport events of air pollution originating from outside California.

- *Timeline* -

- October 2007 – December 2007:
    - Validate instrument performance.
    - Purchase new instruments and equipment;
    - Instrument development and installation.
    - Develop a coordination plan with NASA.

- January 2008 –September 2008
    - Profiling flights to measure aerosol, gas and irradiance every 2 to 4 weeks.
    - Two intensive periods of several flights in a one-week period.
    - Concurrent data analysis.

6. PROJECT MANAGEMENT

Through our previous experience, we have developed a field operations and management plan to optimize platform operations and data collection. Scripps Institution of Oceanography and NASA Dryden will handle the operation of the aircraft in the field. Scripps will integrate and operate the instrumentation, operate the flight ground station, and control the aircraft flight plan. NASA will handle flight operations and airspace control. NASA's responsibility includes insurance for damages to platforms and liability for property damage, amongst others. NASA will provide the aircraft engineers, RC (radio control) pilots, and range safety officer. Details of the overall management plan is given below:

Management Plan

V. Ramanathan, co-Principal Investigator (Lead)

1. Responsible for the overall conduct of the experiment
2. Direct scientific goals.
3. Assist with flight plans.

Craig Corrigan, co-Principle Investigator and Flight Scientist

1. Responsible for developing and selecting instrumentation and integrating into AUAV platform.
2. Responsible for flight planning.
3. Operation of flight ground station.
4. Responsible for collected data.

Hung Nguyen, Mission Director

1. Negotiate to obtain airspace and flight operational status from the military and FAA
2. Develop and adjudicate operational agreements between SIO and NASA.
3. Coordinate and adjudicate between SIO and ACR Company for aircraft technical and flight operations issues.
4. Ensure safety of operations and compliance to all government requirements and regulations

Greg Roberts, co-Investigator

1. Provide expertise on instrumentation and data acquisition system.
2. Integrate new instrumentation into data acquisition software.
3. Serve as a backup mission leader and ground station operator.

Muvva Ramana, co-Investigator

1. Provide expertise on radiometers and collected radiation data.
2. Assist in field operations.
3. Serve as a backup mission leader and ground station operator.

Technician, To be named

1. Responsible for preparing aircraft instrumentation.
2. Monitoring aircraft instrumentation during flight.
3. Operation of data ground station.
4. Assist with development of new instrumentation.
5. Assist in field operations.

7. BUDGET JUSTIFICATION

We anticipate having the concurrent projects utilizing and developing the AUAV systems that will contribute to the science of this CEC based proposal. Primarily, the Scripps team will work with NASA for operating the aircraft. In addition, the team will be using collected data for validation of and comparison to satellite products (Calypso, Aqua, GOME). Furthermore, the team will be using existing research to apply towards the possible development of additional gas instrumentation (NO_x, SO_2, CO_2) as well as the possibility of additional flight operations near Trinidad Head, CA in coordination with other projects such as PACDEX and WPAC.

The primary salary support listed in the budget is for the support of Dr. Craig Corrigan. Dr. Corrigan will be working with Dr. Ramanathan in obtaining the proposed project's objectives. Salary support for Greg Roberts and Muvva Ramana is budgeted for their assistance during part of the experiment. The limited support of a programmer and graduate student will assist with development of the new gas instruments. A technician is budgeted to assist with the aircraft missions and field measurements. Dr. Ramanathan's participation to this project will be at no charge.

Project specific costs that include telephone equipment, tolls, voice and data communication charges, photocopying, faxing, postage, and other research related supplies and materials are requested. Supply and expense items, categorized as project specific, and computer and networking services are for expenses that specifically benefit this project and are reasonable and necessary for the performance of this project.

Equipment:

Several standard sets of instruments exist from previous projects. Two ozone monitors will be purchased from 2B Technologies, Inc. and modified for use in the aircraft. A carbon monoxide monitor will be developed at Scripps. The MAAP instrument will be purchased from Thermo Electron Corp and modified appropriately to fit onboard the AUAV. These instruments are critical for measuring the gas and aerosol properties outlined in the proposal. The proposed funds will purchase necessary replacement parts to ensure continuous operation of the instruments.

Supplies and other expenses:

Logistics support and hardware (electrical cables, tables, tools, shelves, generator, etc) will be needed to operate during the field missions.

Flight operations contract:

The services of a Radio Control pilot will be needed to launch and recover the aircraft. This person will also serve as the aircraft mechanic. NASA will need to provide a field support engineer to coordinate use of the airfield facilities and to maintain custody of the aircraft outside of missions. In addition, a range safety officer will be needed to coordinate with air traffic control and to exercise remote termination of the flight should an emergency situation arise. Cost sharing will be explored with NASA for these services. Further services will be required from ACR to supervise the initial flight missions. Mr. Nguyen will work with NASA and ACR in obtaining these services.

Travel:

Travel costs are separated into two categories. 1.) Travel from Scripps to Dryden by car for 2 to 3 participants for the flight missions and 2.) Travel to ACR company for flight training and to conferences to present the findings.

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